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# FleCSI

a framework designed to support multi-physics application development.


Irina Demeshko

09.01.2020

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LA-UR-20-26483

# FleCSI team

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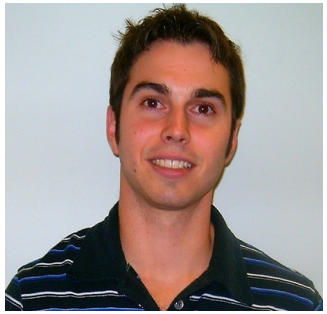

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# FleCSI

- A framework for multi-physics application development.
  - Control model
  - Execution model
  - Data model

Legion,
HPX, MPI

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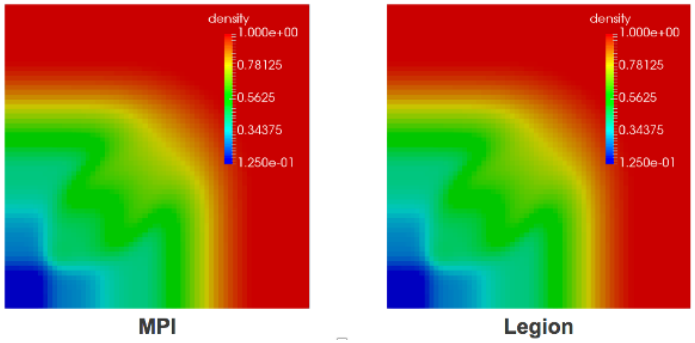
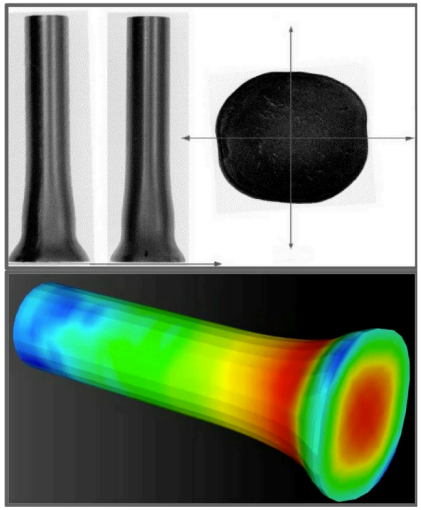
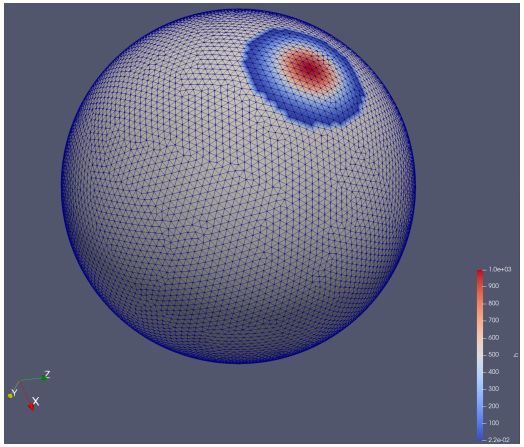



Runtime portability example, shock box



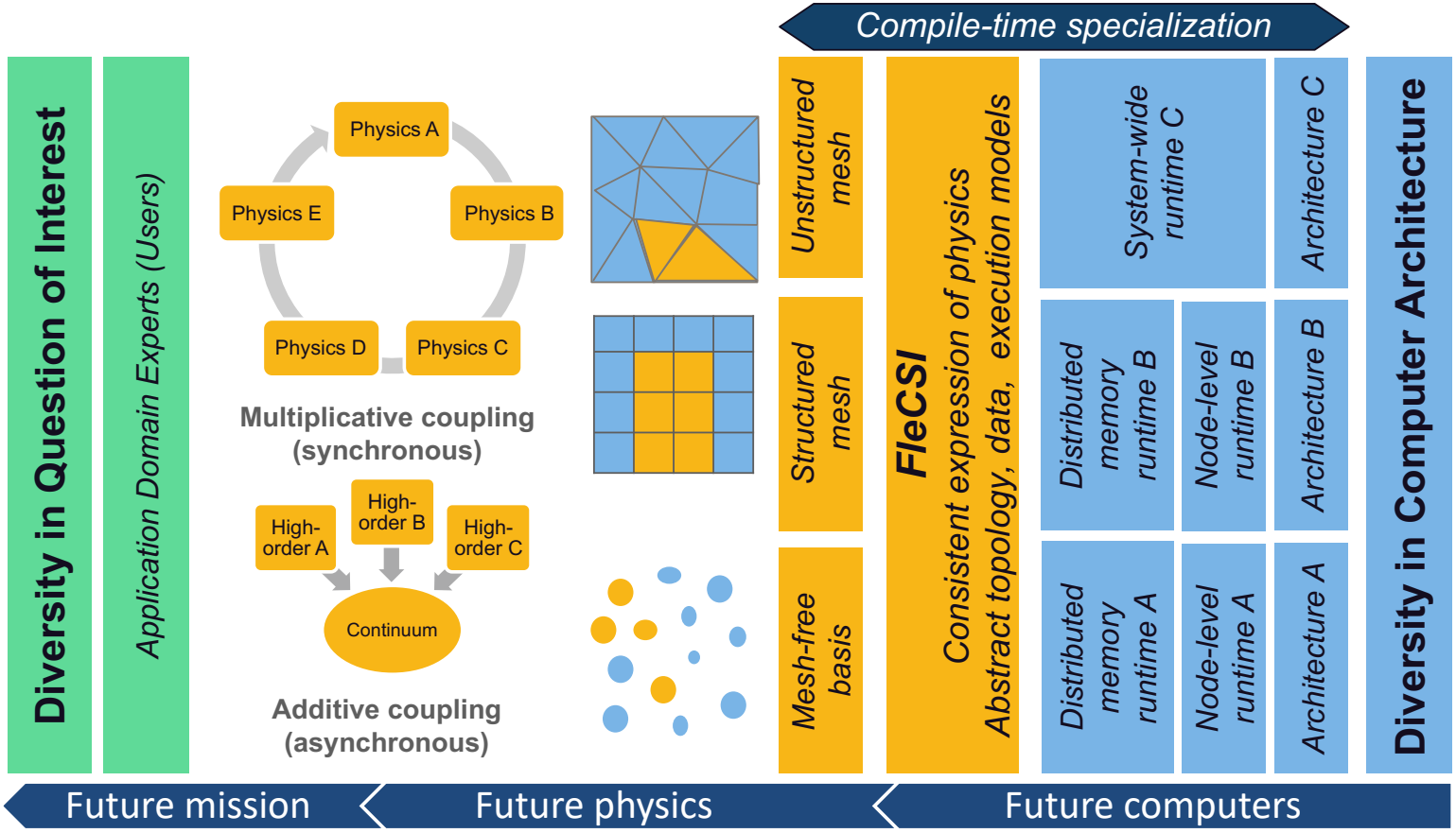
*Higher-fidelity predictive science through multiscale methods: A Flistra hydrodynamics code with an advanced grain-structure-aware material model (bottom image) captures the asymmetric deformation seen in Taylor anvil experiments measuring the behavior of metal under impact (top image). Courtesy: the Flistra project*



shallow water test case 1:
Advection of Cosine Bell over the Pole from the following reference.

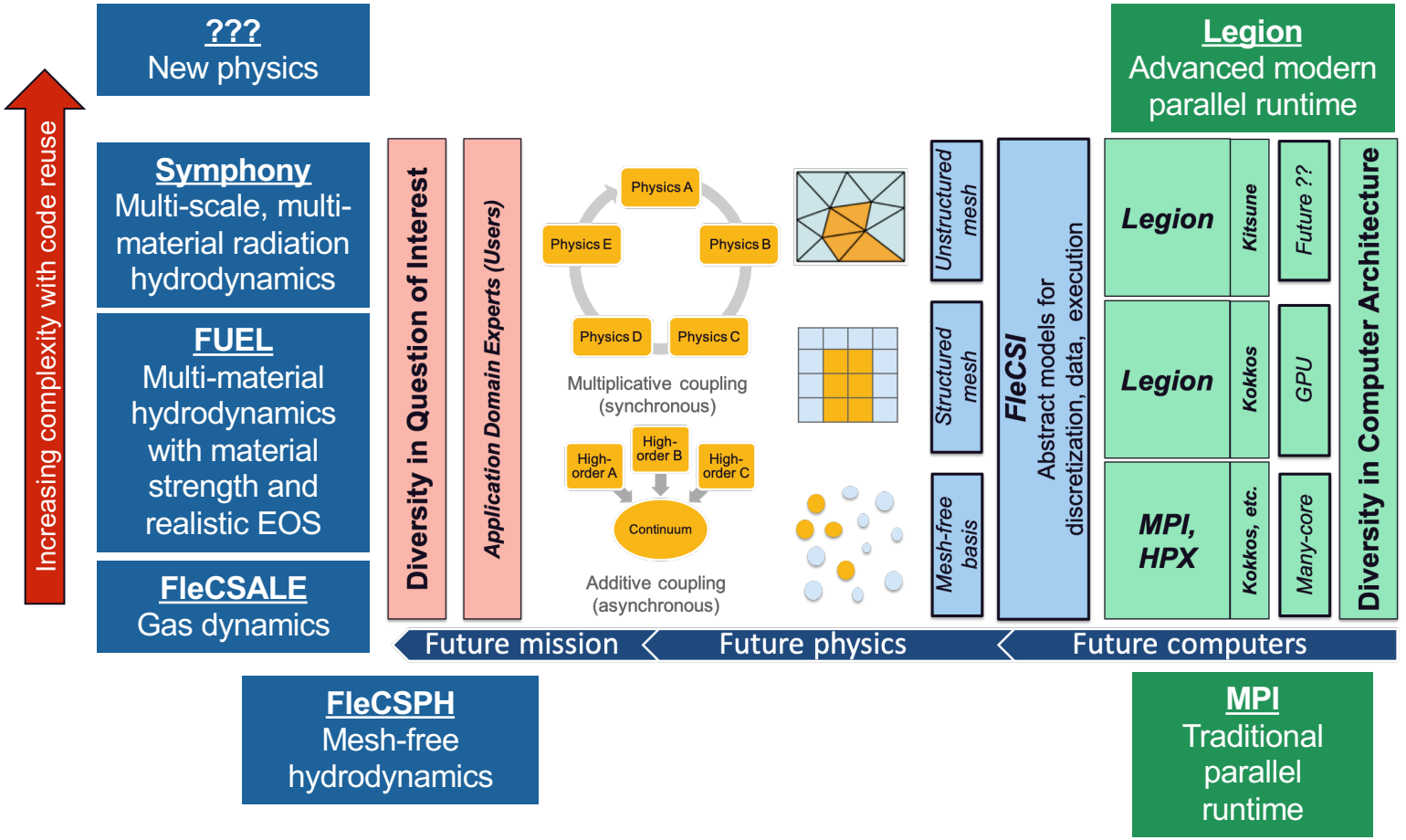
# Ristra goal: Multi-physics code developer productivity

*Realized through FleCSI, a compile-time configurable abstraction layer*



# Ristra SW Architecture: flexibility in a volatile future

*A variety of application codes have been developed using FleCSI*



# FleCSI primary goals

**Simplicity:**

Simplify multiphysics simulation development

Hide complicated logic on how to efficiently execute program on different HPC systems

**Abstraction:**

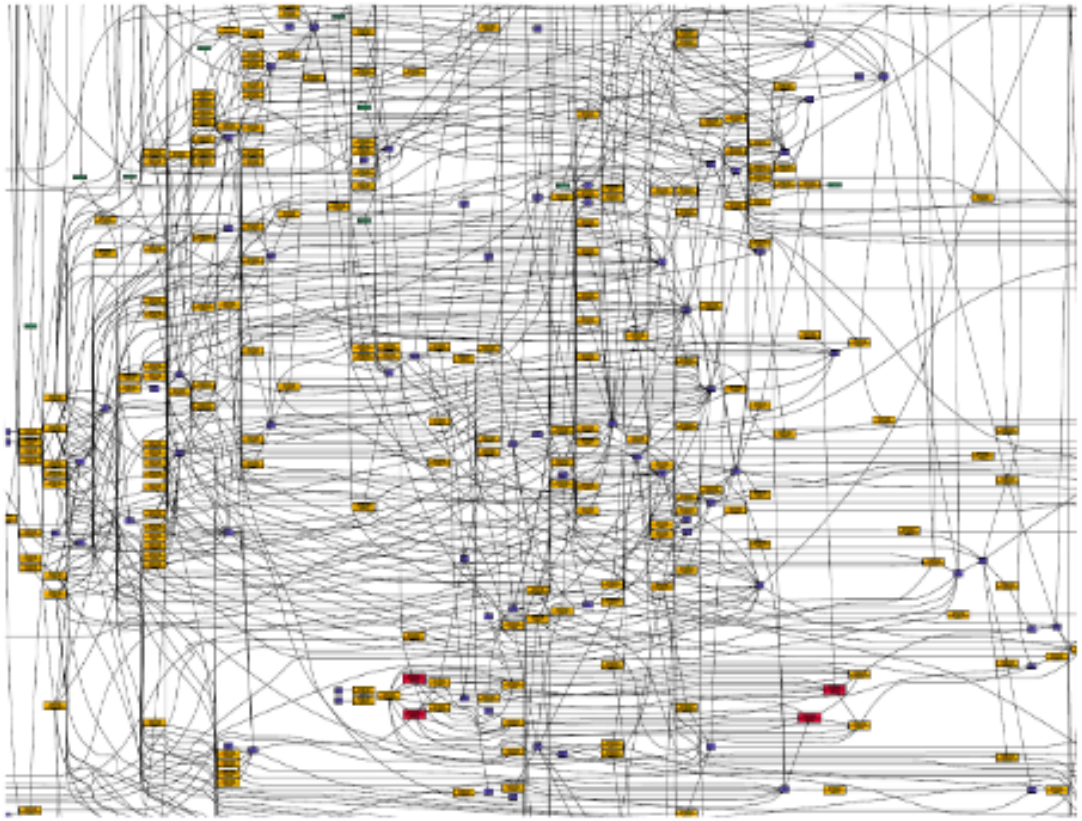
Abstract different run-times/programming models in a single interface

**Flexibility:**

Provide flexibility for target data structures/topology types

**Robustness**

# Why task-based runtimes?



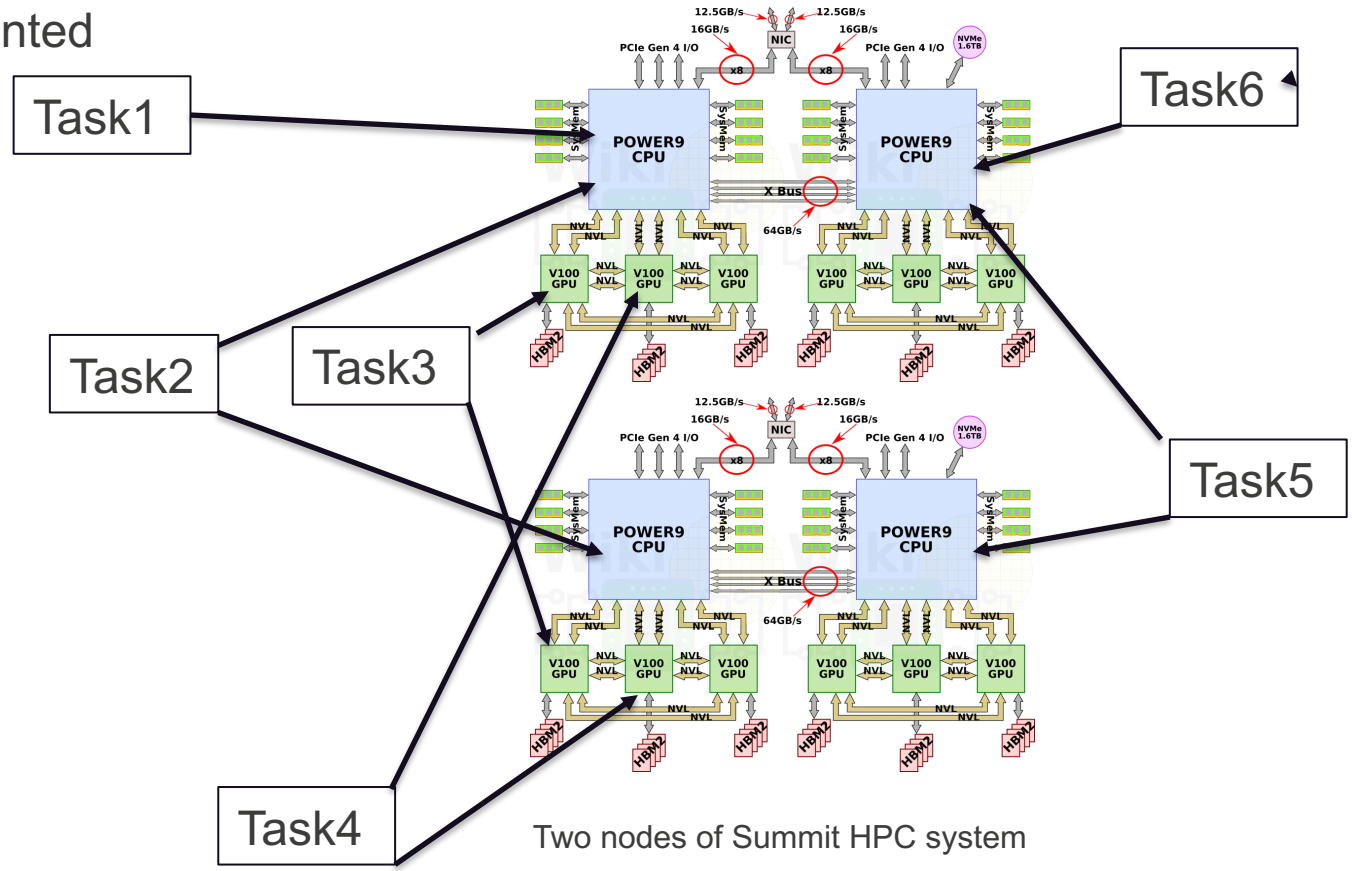
- Do you want to schedule that graph?
  (High Performance)
- Do you want to re-schedule that graph for every new machine?
  (Performance Portability)
- Do you want to be responsible for generating that graph?
  (Programmability)

MPI: programmer's responsibility

AMT: programming system's responsibility

# Legion

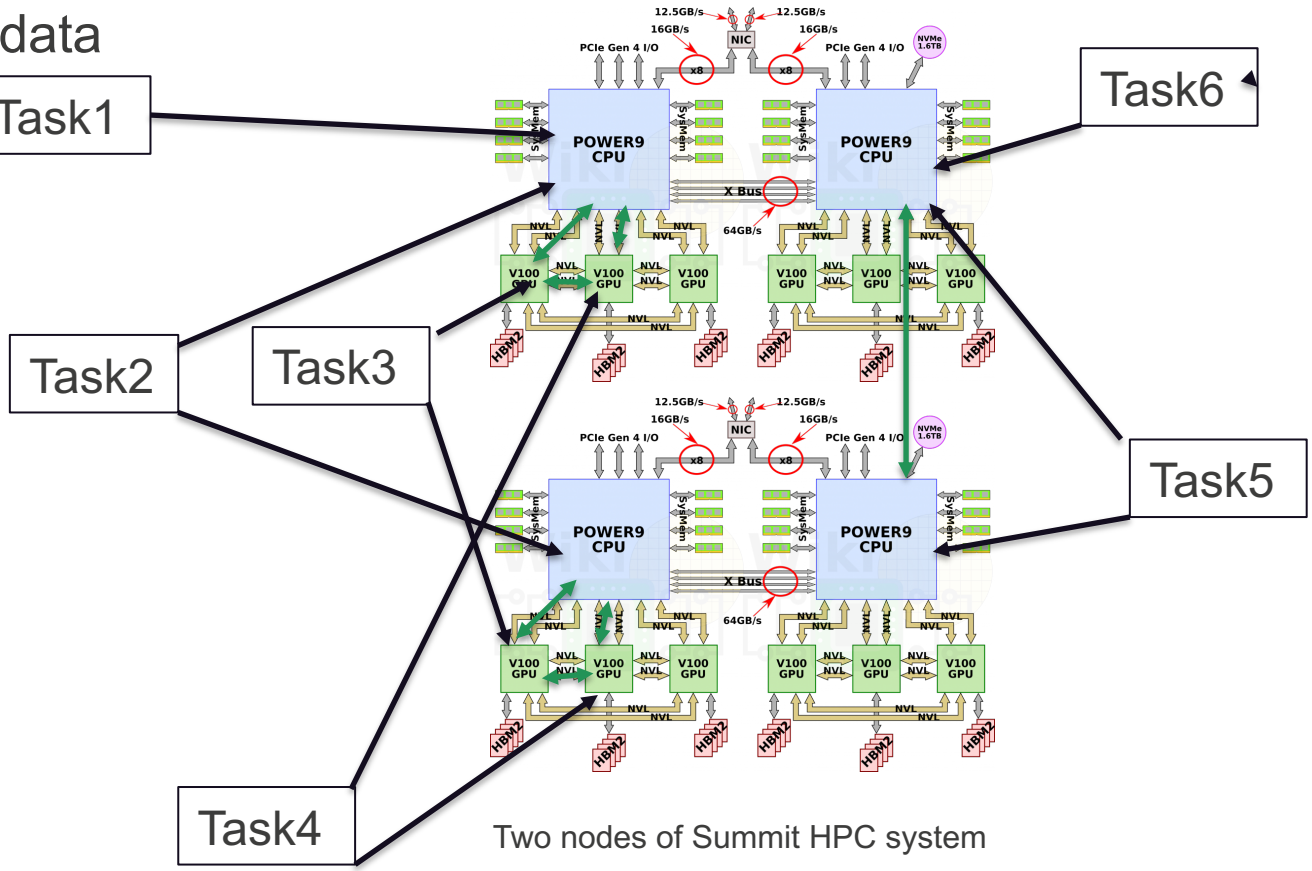
- Automated scheduling and latency hiding
  - Asynchronous tasking
  - Throughput-oriented




Two nodes of Summit HPC system

# Legion

- Easy access to GPUs
  - Simplifies programming complex hardware
- Easy control over data
  - partitioning
  - placement
  - layout in memory
- Kokkos support




Two nodes of Summit HPC system

# FleCSI API (tasks)

```
burton::slot burton;
burton::cslot coloring;

const field<double>::definition<burton, burton::cells> cell_field;
auto pressure = cell_field(burton);

void init(burton::accessor<wo> t, field<double>::accessor<wo> p) {
  for (auto c : t.cells()){
    p(c) = 4.5;
    for (auto v: t.vertices(c){
      ...
    }
  }
} // init

void check(burton::accessor<ro> t, field<double>::accessor<ro> p) {
  for (auto c: t.cells()){
    assert(p(c) == 4.5);
  }
} // init

void driver() {
  coloring.allocate("input.txt");
  burton.allocate(coloring.get());

  execute<init>(burton, pressure);
  execute<check>(burton, pressure);
}
```

# FleCSI API

```
burton::slot burton;
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const field<double>::definition<burton, burton::cells> cell_field;
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void driver() {
  coloring.allocate("input.txt");
  burton.allocate(coloring.get());

  execute<init>(burton, pressure);
  execute<check>(burton, pressure);
}
```

Creates partitioning of the mesh

Creates data containers (arrays, Logical Regions) and metadata for all entities of the mesh + connectivity information for burton_mesh_t type

# FleCSI API

```
burton::slot burton;
burton::cslot coloring;

const field<double>::definition<burton, burton::cells> cell_field;
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void init(burton::accessor<wo> t, field<double>::accessor<wo> p) {
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void driver() {
  coloring.allocate("input.txt");
  burton.allocate(coloring.get());

  execute<init>(burton, pressure);
  execute<check>(burton, pressure);
}
```

Creates ‘pressure` field
on cells index space in a burton mesh

# FleCSI API

```
burton::slot burton;
burton::cslot coloring;

const field<double>::definition<burton, burton::cells> cell_field;
auto pressure = cell_field(burton);

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  for (auto c : t.cells()){
    p(c) = 4.5;
    for (auto v: t.vertices(c){
      ...
    }
  }
} // init

void check(burton::accessor<ro> t, field<double>::accessor<ro> p) {
  for (auto c: t.cells()){
    assert(p(c) == 4.5);
  }
} // init

void driver() {
  coloring.allocate("input.txt");
  burton.allocate(coloring.get());

  execute<init>(burton, pressure);
  execute<check>(burton, pressure);
}
```

Execute FLeCSI task

# FleCSI API (tasks)

```
burton::slot burton;
burton::cslot coloring;

const field<double>::definition<burton, burton::cells> cell_field;
auto pressure = cell_field(burton);

void init(burton::accessor<wo> t, field<double>::accessor<wo> p) {
  for (auto c : t.cells()){
    p(c) = 4.5;
    for (auto v: t.vertices(c){
      ...
    }
  }
} // init

void check(burton::accessor<ro> t, field<double>::accessor<ro> p) {
  for (auto c: t.cells()){
    assert(p(c) == 4.5);
  }
} // init

void driver() {
  coloring.allocate("input.txt");
  burton.allocate(coloring.get());

  execute<init>(burton, pressure);
  execute<check>(burton, pressure);
}
```

FleCSI task

# FleCSI API (tasks)

```
burton::slot burton;
burton::cslot coloring;

const field<double>::definition<burton, burton::cells> cell_field;
auto pressure = cell_field(burton);

void init(burton::accessor<wo> t, field<double>::accessor<wo> p) {
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  }
} // init

void check(burton::accessor<ro> t, field<double>::accessor<ro> p) {
  for (auto c: t.cells()){
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  }
} // init

void driver() {
  coloring.allocate("input.txt");
  burton.allocate(coloring.get());

  execute<init>(burton, pressure);
  execute<check>(burton, pressure);
}
```

Data access permissions

- Used to create task dependency graph by Legion
- Used to reason about data exchange by FleCSI
- The dual use of the privileges is important

# FleCSI API (tasks)

```
burton::slot burton;
burton::cslot coloring;

const field<double>::definition<burton, burton::cells> cell_field;
auto pressure = cell_field(burton);

void init(burton::accessor<wo> t, field<double>::accessor<wo> p) {
  for (auto c : t.cells()){
    p(c) = 4.5;
    for (auto v: t.vertices(c)){
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    }
  }
} // init

void check(burton::accessor<ro> t, field<double>::accessor<ro> p) {
  for (auto c: t.cells()){
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  }
} // init

void driver() {
  coloring.allocate("input.txt");
  burton.allocate(coloring.get());

  execute<init>(burton, pressure);
  execute<check>(burton, pressure);
}
```
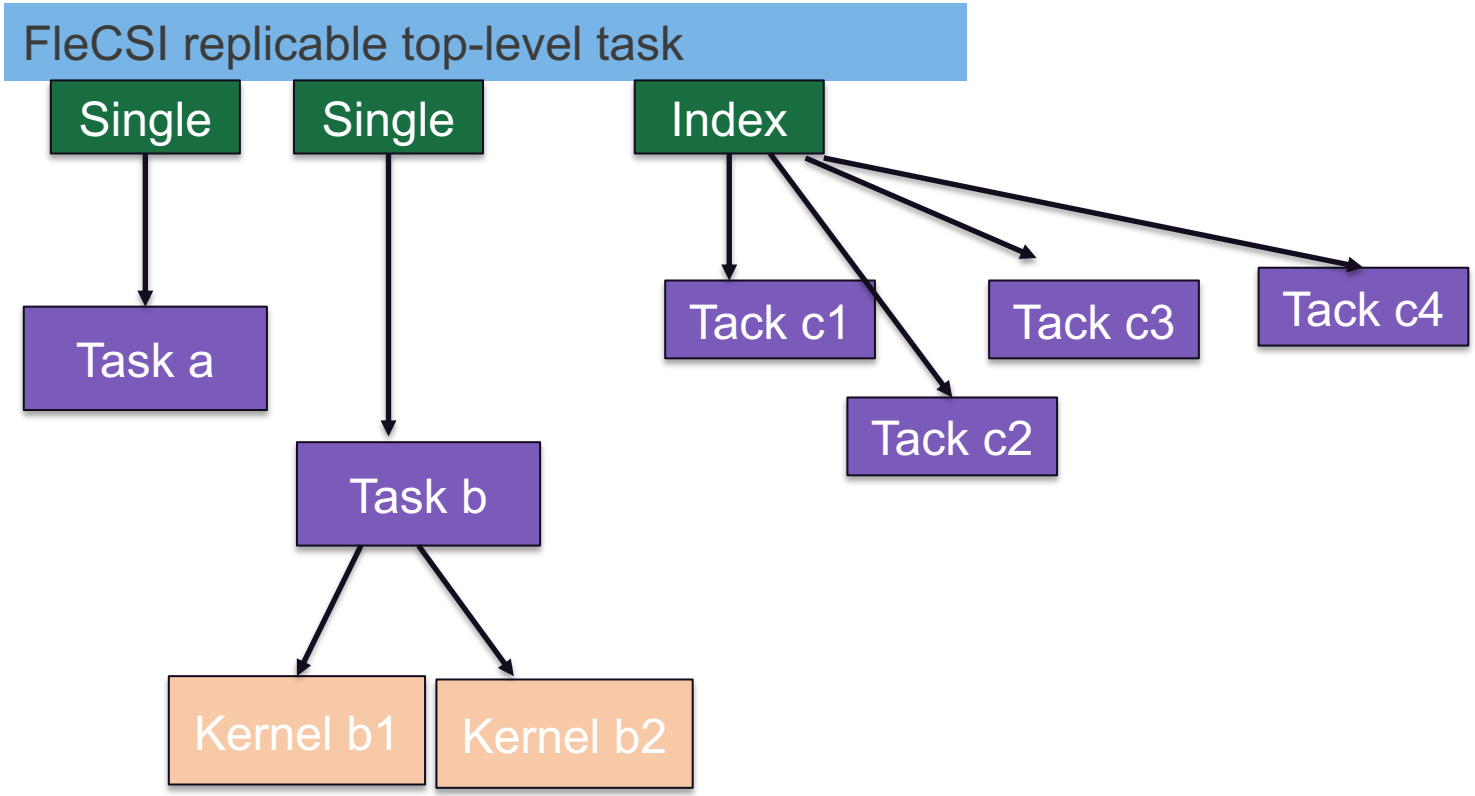

## FleCSI iterators

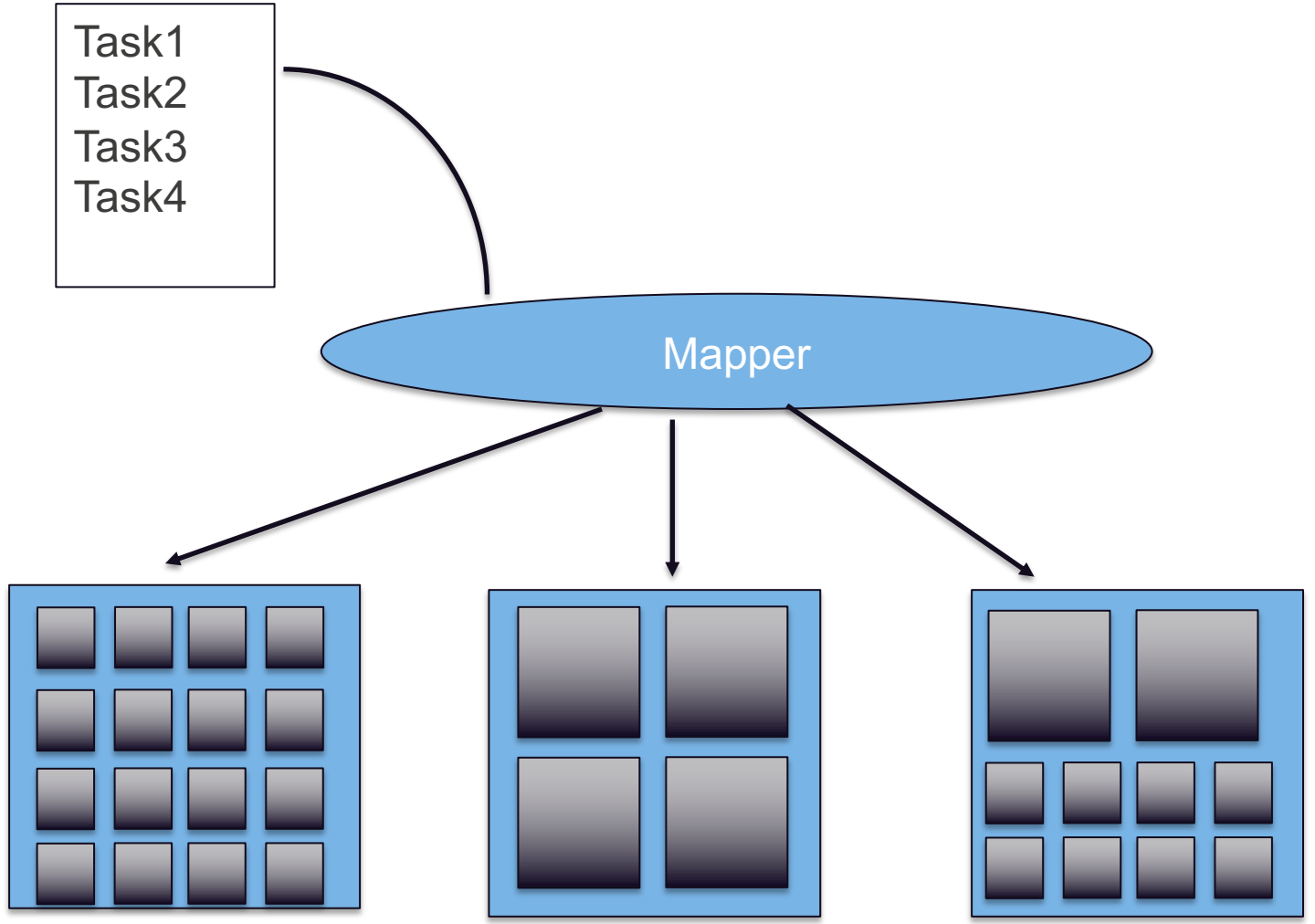
- Provide intuitive data access
- Work inside Kokkos

# FleCSI Execution model




Launch type

# FleCSI mapper



# FleCSI API ( tasks + kernels)

```
burton::slot burton;
burton::cslot coloring;

const field<double>::definition<burton, burton::cells> cell_field;
auto pressure = cell_field(burton);

void init(burton::accessor<wo> t, field<double>::accessor<wo> p) {
  forall (auto c, t.cells()){
    p(c) = 4.5;
    for (auto v: t.vertices(c){
      ...
    }
  };
} // init

void check(burton::accessor<ro> t, field<double>::accessor<ro> p) {
  for (auto c: t.cells()){
    assert(p(c) == 4.5);
  }
} // init

void driver() {
  coloring.allocate("input.txt");
  burton.allocate(coloring.get());

  execute<init, toc>(burton, pressure);
  execute<check, loc>(burton, pressure);
}
```

# FleCSALE

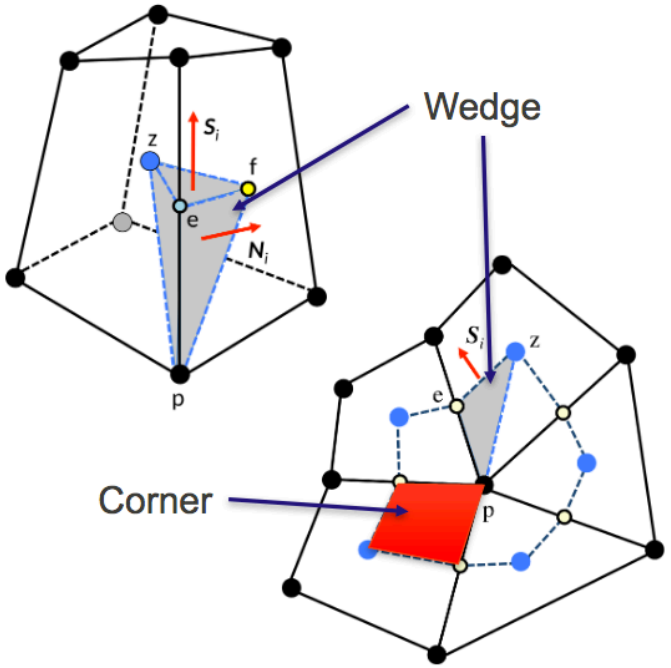
- FleCSALE - continuum dynamics software packages built on top of FLeCSI.
- Current status:
  - 2D/3D cell-centered Eulerian and Lagrangian solvers
  - 3D FEM Lagrangian solver

**Mesh is templated on dimension:**

**2D:**
```
burton_mesh_t<2> mesh;
```
**3D:**
```
burton_mesh_t<3> mesh;
```

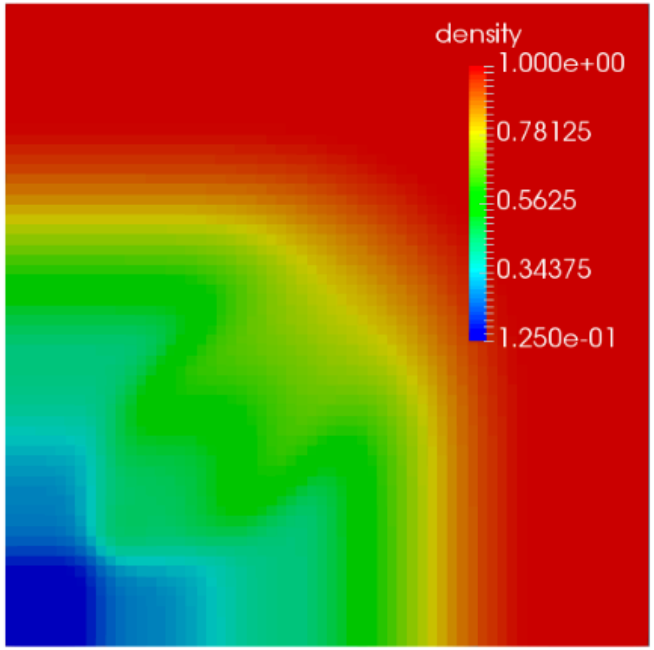
**Application code doesn't change (code works in 2D and 3D):**
```
for ( auto f : mesh.faces() )
  auto n = f->normal();
  // do some work
```

**Mesh has wedges and corner data structures in addition to vertex, edge, face, and cell primitives:**
```
for ( auto cn : mesh.corners() )
  for ( auto wg : mesh.wedges(cn) )
    auto n = wg->facet_normal();
    // do some other work
```

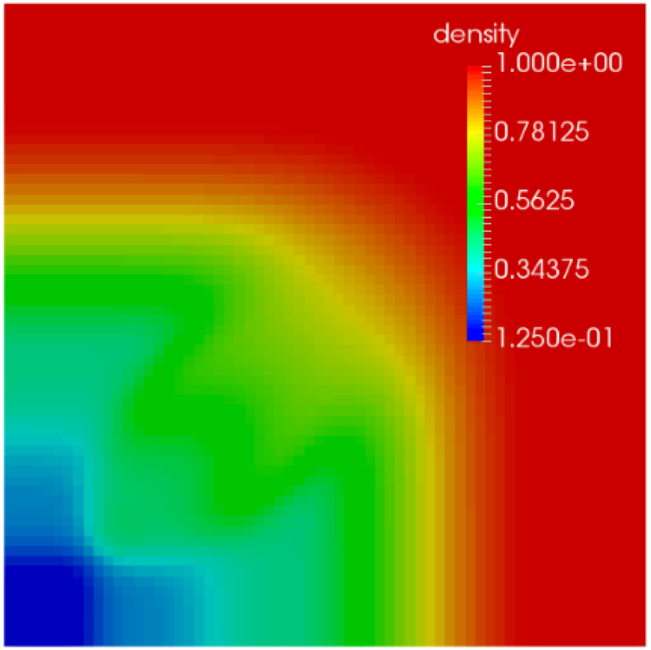


## FleCSALE Runtime Portability

**FleCSI allows switch between MPI and Legion runtime models with no change to application code**

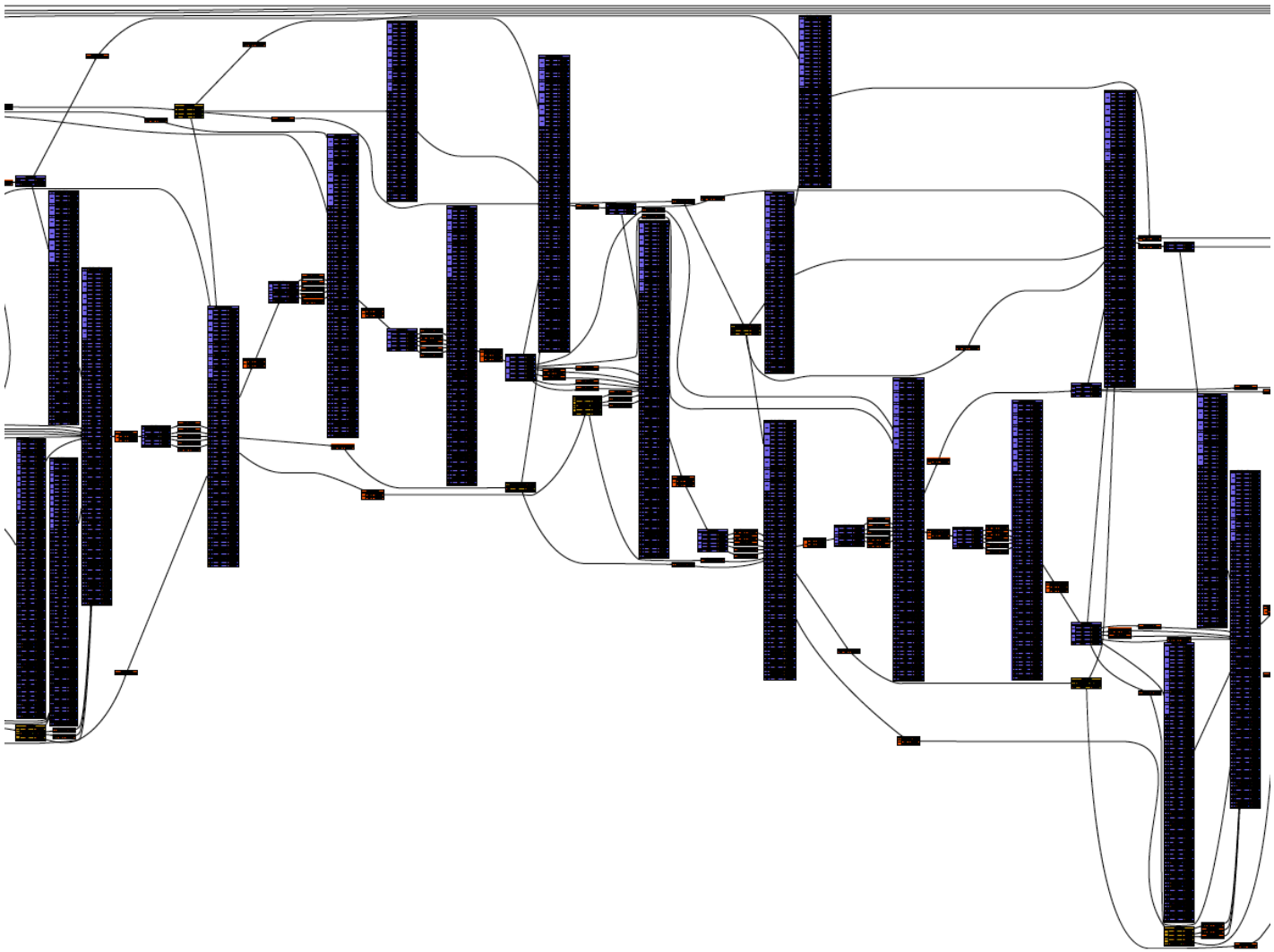



MPI

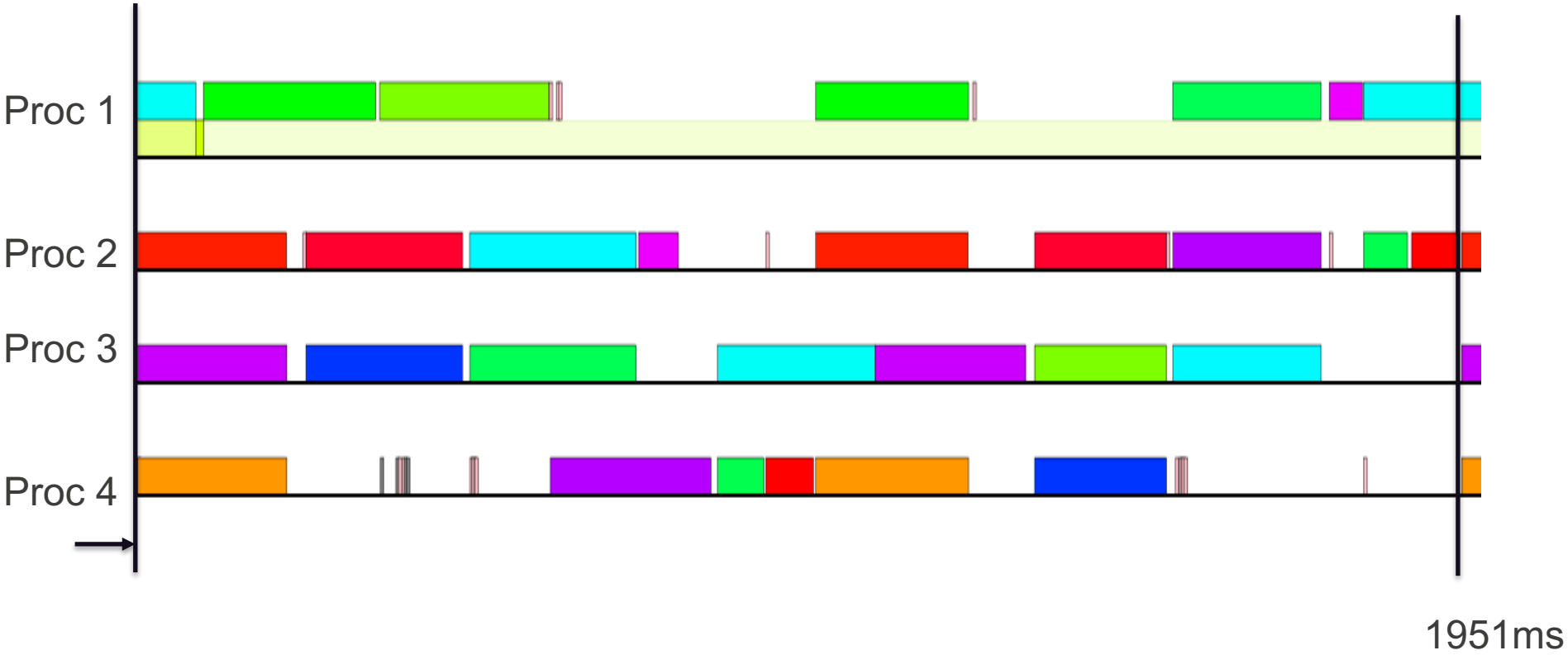



Legion

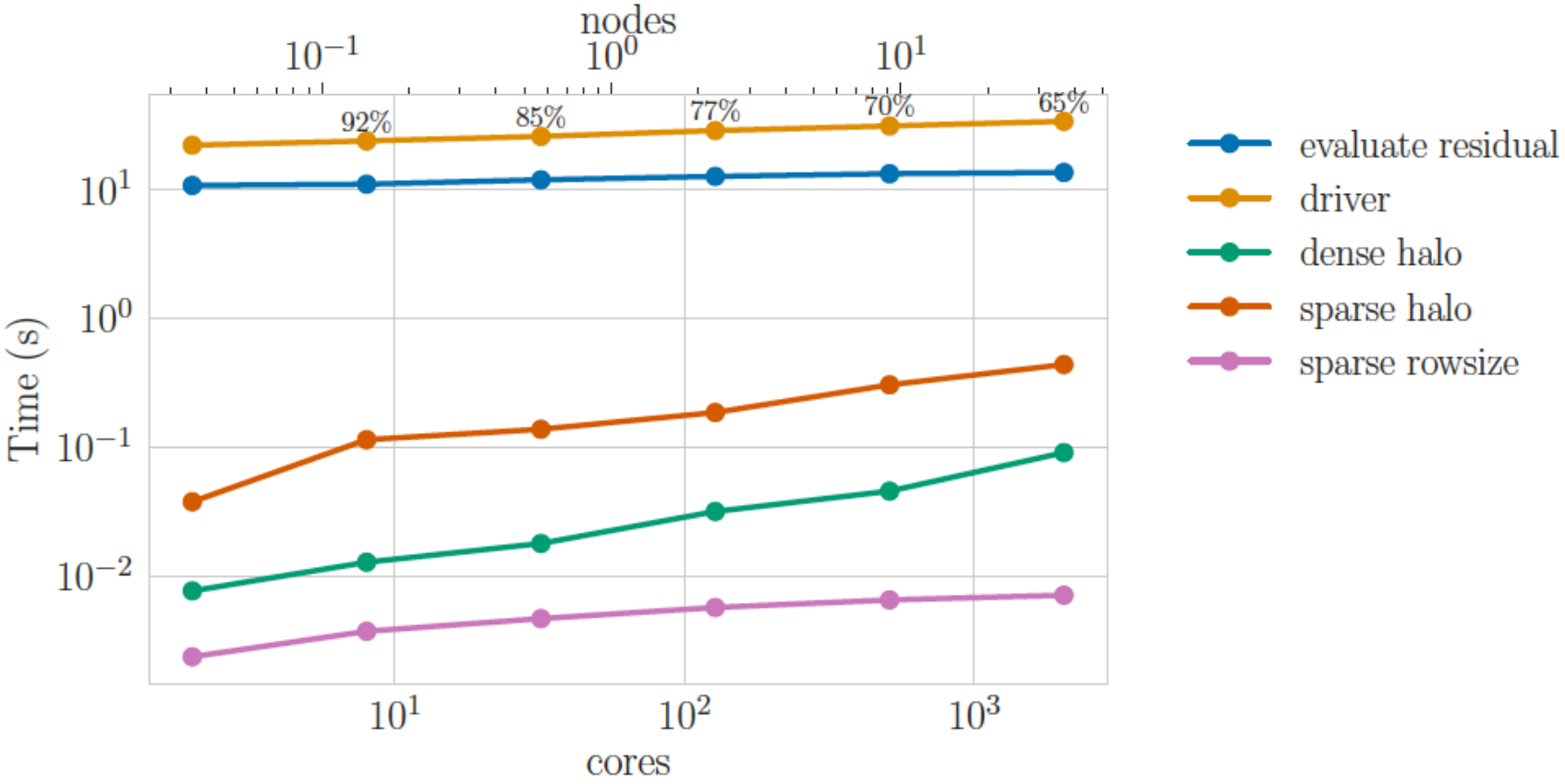
# Profiling results (FleCSALE, hydro_2d)



# Legion Prof output



# Weak Scaling results (maire_hydro_2d, MPI)

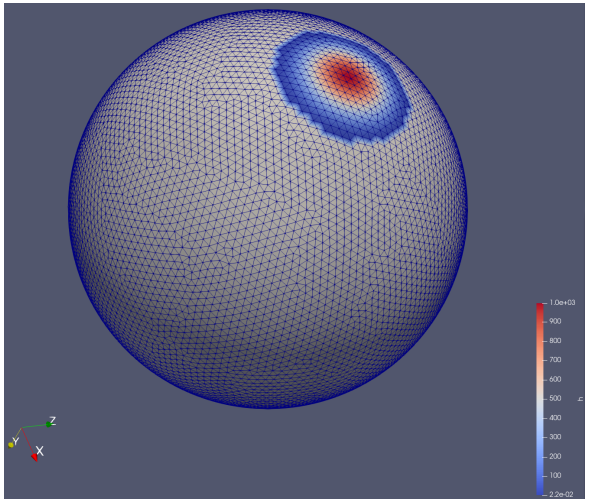


# MPAS-Ocean

MPAS-Ocean is designed for the simulation of the ocean system from time scales of months to millenia and spatial scales from sub 1 km to global circulations.

***Current status*** of MPAS-O-FleCSI:

- advection – diffusion application
- shallow water application



shallow water test case 1: Advection of Cosine Bell over the Pole from the following reference.

**CANGA**
**Coupling Approaches for Next-Generation Architectures**

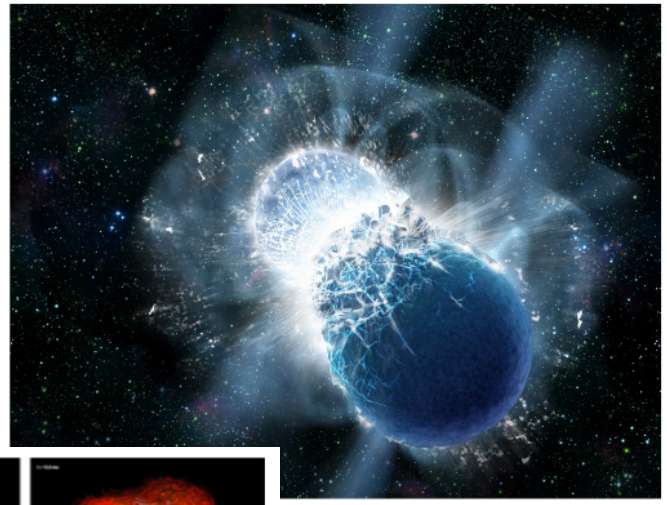
# FLeCSPH

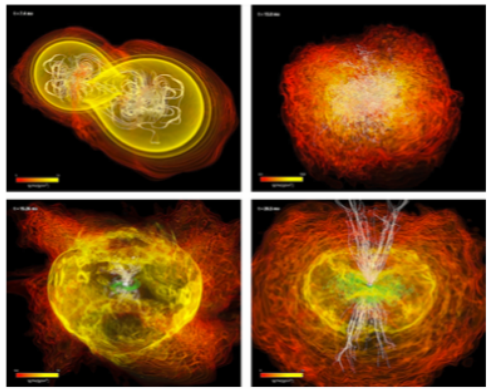

smoothed-particle hydrodynamics (SPH) solver for the solution of Lagrangian problems in astrophysics and cosmology.

**Uses FleCSI tree topology**

**Initial focus on astrophysics simulations of neutron star merges**

Potential source of gravitational waves, macronovae, and nucleosynthesis





Rezzola et al. (2011)


: Performance Portability Programmability

Would like to find more ?

https://flecsi.org/